Future bulk grain bin design needs related to sealing for optimum pest management — a researcher's view.

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Abstract

For decades, U.S. grain elevators have experienced fumigation failures in steel bins due to inadequate sealing of bins. At this time, U.S. grain bin manufacturers normally do not sell bins with seal kits as standard equipment and not all manufacturers have adequate kits to seal the bin wall panel joints and other openings in the bin base, sidewall, and roof. Aeration and drying fans, conveyors, and sidewall access doors are not designed for insect exclusion and are difficult to seal adequately.

Research has shown that the headspace in steel bins should not be totally sealed, except during fumigation or controlled atmosphere treatment, as this can cause storage damage from condensation if the grain manager does not monitor the grain adequately. However, U.S. grain elevators and farmers should be able to purchase bins with base and sidewalls that are sealed or "sealable." Steel bin roofs should be designed to exclude insects and allow movement of fresh air through the headspace, but which can be quickly sealed during bin treatments. Newly constructed sealed bins should be capable of meeting a voluntary U.S. bin sealing standard, which should be developed.

Research also indicates there are other storage design improvements that should be incorporated into the standard bin design. For example, white-painted bins keeps grain cooler and flat bottom bins can be made self-cleaning using advanced aeration system designs to eliminate insect harborages in the bottom of future steel bins.

Keywords: Sealing; Bolted Steel Grain Bin; Fumigation; Controlled atmosphere

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Background

Leesch et al. (1995) stated that inadequate sealing of bins is the leading cause of fumigation failures. Bolted steel bins, with many joints and openings, are particularly problematic. Seal kits are not standard equipment from U.S. grain bin manufacturers and not all manufacturers have adequate kits to seal the bin joints and openings to a tightness level that will retain phosphine gas. Currently, bins are designed with a number of openings for augers, fans, and doors that are not designed for insect exclusion and are difficult to seal adequately. When fumigation, controlled atmosphere (CA), or modified atmosphere (MA) treatments are required, these openings become a source of leakage that can render the treatment ineffective. In some climatic regions of the U.S.,

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This presentation accepted for Proceedings of the Controlled Atmosphere and Fumigation Conference, October 29 – November 3, 2000 Fresno, California.

fumigation is an integral part of the stored grain management plan. In other areas, fumigation is used when problems arise.

Geographically Specific Grain Storage

Geographically specific grain storage structures and management techniques can be used to address the different levels of severity of insect problems in different climatic regions. Storey et al. (1979) characterized the different regions of the U.S. based on severity of risk based on storage insect problems. The four regions they delineated (Fig. 1) are correlated with the expected effectiveness of grain aeration strategies in Table 1. States in Region 1 can manage grain effectively for insect control with aeration alone. Region 2 states can do the same with fall harvested crops, as well as with summer crops with automatically controlled aeration. Simulation studies indicate that Region 3 states should generally be able to do well with automatically controlled aeration alone for fall crops (Arthur, et al., 1998), as well as with summer aeration of summer crops (Arthur and Flinn, 2000). Chilled aeration (Maier and Rulon, 1996) could provide a non-chemical tool to facilitate grain storage in all four regions; and is especially applicable in Regions 3 and 4 where the warm climate reduces the effectiveness of aeration. Also, promising results of automatically controlled conventional aeration have been reported for Region 3 (Harner and Hagstrum, 1990; Reed and Harner, 1998a, 1998b). Most parts of Region 4 are unlikely to be successful with conventional aeration alone, especially in the warmer part of this region and when storing grain into the next summer, based on simulation studies (Arthur and Johnson, 1995; Arthur, et al., 1998).

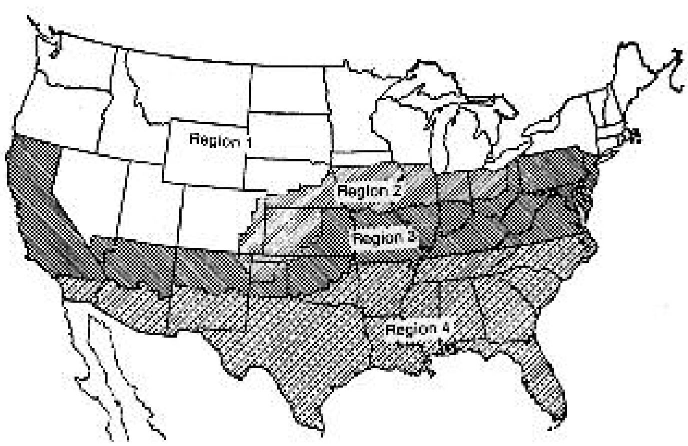

Figure 1 – Regions of the United States based on stored-grain insect risks (Storey et al., 1979).

Table 1 shows that two-thirds of the U.S. wheat and corn production is in regions (1 and 2) where aerated storage can readily be very effective. Unfortunately, the potential benefit of aeration is not always realized in practice, and fumigation applications will continue to be needed in locations where the climate should permit them to be avoided. Educational efforts should improve this prognosis, but there have been many years of educational efforts in the past, yet potential benefits are not always achieved. It appears that with the climate in Region 1, problems from insects can be easily overcome with aeration and simple management practices, so that fumigation will not be needed. To date, application of aeration and proper management has not reached the level to eliminate the need for fumigation; however, this region might see equal benefit from aggressive education programs compared with improving bins with easier and better sealing methods.

In Region 2, the potential exists to handle insects almost as well as in Region 1 using good aeration practices, especially with fall crops that dominate production in this region. However, there is also often the potential for greater insect problems here, more comparable to Region 3. It is likely that fumigation will continue to be important in many cases even in Region 2, although education could greatly reduce the need for fumigation in this region. In Region 3, where the climate leaves little margin for error, fumigation will undoubtedly continue to be important even where reasonably good aeration management is practiced. Chilled aeration or other novel management practices are required to supplement closed loop fumigation (CLF) or other chemical treatments in Region 4.

Table 1 – Regional variation in aeration effectiveness for insect control in farm-stored grain.

Region*	Aeration Potential	Percent of U.S. Wheat and Corn Production
1	Aeration alone sufficient.	**34.4 %**
2	Aeration alone sufficient – management important.	**33.1 %**
3	Aeration alone “arguably” sufficient – management critical.	**24.1 %**
4	Aeration alone not sufficient – especially through summer.	**8.5 %**

* Storey et al, 1979.

Research on Fumigation and Controlled Atmosphere Applications

Banks (1978, 1984) reviewed research on fumigation and controlled atmospheres in grain storage. That work, much of it in Australia, identified equipment and procedures required for successful treatments. Since then, there have been efforts to model CO_2 movement during CA treatment of stored grain (Alagusundaram et al. 1996) and further work is currently underway. Fumigation models are also being developed. Annis and Banks (1993) developed a prediction equation for phosphine concentration in the interstitial air in stored grain and Banks (1993) developed a prediction equation for phosphine sorption in grain kernels.

Noyes and Kenkel (1994) demonstrated that a well-sealed bin allowed the use of closed loop fumigation (CLF), which provided good insect control at lower dosages than probe fumigation. Cook (1980) patented a low -volume recirculation method that pushed the fumigant and air mixture into the bottom of the bin, up through the grain, then recirculated the mixture from the headspace and back through in a closed loop process. CLF was more efficient than probe fumigation because it required less fumigant per treatment. It reduced or eliminated bin entry and worker exposure to the chemical and eliminates the need for turning the grain in deep bin applications — with the added cost and losses that occur when additional turning is required. Grain bin manufacturers should offer CLF kits as well as aeration and temperature monitoring auxiliary products.

Research on Sealing Bins

Research on sealed grain storage bins has shown two overriding benefits. A properly sealed bins allows effective fumigation (at lower fumigate rates and improved efficacy than is otherwise possible) or use of controlled atmospheres for insect control, and a sealed bin is more resistant to re-infestation by insects after successful treatment (Banks, 1978). The ability to easily seal bins against insect immigration is useful in all regions, even Region 1 with its limited insect problems. However, the success of fumigation and CA treatment in any climate is dependent on having a sufficiently well sealed system to prevent gas loss that reduces the concentration below effective levels for insect control (Leesch et al., 1995).

Research indicates that the headspace in steel bins should not be totally sealed, except during fumigation or CA/MA treatment, as this can create storage damage if the grain manager does not monitor the grain adequately (Noyes, 1991). A sealed headspace is subject to significant moisture condensation conditions, which cause grain damage. The headspace acts as a solar collector, which warms the grain mass, driving the moisture transfer process and introducing heat that accelerates insect development. Exclusion designed vents that allow air circulation but block insect entry is a way to limit warming and insect activity.

Reed and Pan (2000) showed that the commonly applied procedure of sealing steel bins only at ground level does not maintain a fumigant gas level sufficient for good insect control under most storage conditions. They did find that this fumigation procedure might be effective at higher grain temperatures. At 30°C the rapid insect development rate meant that the relatively short exposure (before excessive gas leakage losses) resulted in a lethal concentration for at least 2 days after one-half the egg development time for the lesser grain borer at low grain moisture contents (11.5% m.c.) However, this limited ground level sealing is more likely to be effective in the case of CO_2 treatments because this heavier-than-air gas (2.48 specific gravity) leaks from the lower portion of bins.

Alagusundaram et al. (1995) studied the effectiveness of CO_2 treatments in bolted steel bins in Canada. Apparently, the only sealing on these bins was of the entry door and "visible holes." They found that, because of excess leakage in these bins, it was not possible to maintain the high CO_2 concentration necessary for complete control of the rusty grain beetle in short-duration (4 day) treatments. They hypothesized that a longer duration treatment of four to six weeks would give much better control of the rusty grain beetle. White et al. (1990) found such a long-duration, low concentration regime did control the rusty grain beetle in laboratory tests with comparable conditions.

A Sealed Bin Management System

The concept of sealed grain storage systems has been developed and implemented in several countries (including Australia). However, in the U.S., sealed storage bins for dry grain are scarce. Some possible reasons for this scarcity are: 1) A strong reliance on chemicals — enough chemicals to cure whatever problem arises. 2) There are cheap ways out — typically, buggy grain can still be marketed with a price penalty, if it cannot be blended in with enough sound grain to make grade. If the owner of the bad grain is not in position to do the blending, they can generally find somebody to sell it to who is in a position to blend. There is a price penalty, but often not too severe because of blending alternatives. 3) There are cheaper ways to store grain — much of the grain in the U.S. (65 to 90% of the wheat and corn, as indicated in Table 1) is produced in climatic regions where it is possible to store grain quite well without any "novel" (and more expensive) system. Even when insect populations build up in these regions, managers are able to control them with conventional methods.

Research has shown that in climatic regions that cannot achieve complete insect control with aeration alone, fumigation and controlled atmosphere (CA) strategies have the potential to control insects. However, the effective use of these strategies requires bins with adequate sealing for the intended treatment. The benefits of sealed bins are important in any climatic region. The extra resistance to insect invasion and ability to fumigate effectively and efficiently is always advantageous. With the implementation of well-sealed steel bins, CLF can be easily implemented.

Also, as residual chemical control means become less desirable or available, sealed bins will be even more important as a means to use controlled atmospheres to control stored grain insects.

U.S. grain elevators and farmers should be able to purchase bins with base and sidewalls that can be sealed, so that sealed bins can be constructed that are capable of meeting a U.S. bin sealing standard. Noyes (1997) listed five comprehensive design objectives developed by a U.S. working group on future storage systems. Fundamental to those design objectives was the development of sealed structures that will facilitate cost-effective and successful fumigation and CA treatments.

The top of the bin requires considerable design flexibility; it must allow headspace ventilation but still preclude insect entry. The ventilation system should be easily sealed for fumigation treatments. With the roof to sidewall eave joint sealed, adequate overall headspace ventilation through roof vents becomes crucial to avoid condensation problems with upflow ventilation systems. Roof hatches can be designed to exclude insects and seal against gas loss when closed (using quality gaskets and latches). Loading and unloading equipment requires designs that are readily sealed during treatments. It is preferable to seal sidewall joints by installing adhesive backed closed cell foam strips at the time of construction. Like hatches, sidewall doors should be inherently capable of sealing without requiring additional coverings.

Major leakage and entry sources often overlooked are downspouts and horizontal fill conveyor fill points through roof hatches. Both of these types of opening must be sealed for successful fumigation treatments. Gravity counter balanced flap valves are one excellent possibility. Gravity flap valves also keep moist air from going up fill spouts and condensing (MWPS, 1974). Roof vents need double screens (separated by 3 – 5 cm) that will exclude adult insects and trap immature insects that hatch inside the first screen (females will deposit eggs through vent screens).

Other Issues

Research also indicates there are other storage design improvements that should be incorporated into the standard bin design. For example, white painted bins keep grain cooler. Calderwood (1964) found that rice stored in white bins in Texas was about 3°C (5°F) cooler than that in darker colored bins. The temperature of headspace air in these white-painted bins was dramatically cooler (13°C; 24°F) than in the darker bins. Because of this advantage, white bins have long been a standard recommendation in some locations (e.g. Australia; see Banks and Ripp, 1984). The reduction in temperature afforded by the cooler color produces less favorable temperatures for insect growth in the upper portion of grain storage bins. This results in fewer insects and/or less cost to keep the temperatures down to a desirable level with aeration or chilling.

Automatic control of aeration based on ambient temperatures is an inexpensive method to improve the efficiency of aeration systems. Simple automatic controllers will both reduce the time required for aeration management and improve the grain quality compared to manual control. Reed and Harner (1998a, 1998b) showed that during on-farm storage a simple aeration controller—consisting mainly of a high-limit thermostat and an hour meter—cooled summer-harvested grain more quickly and with less cost than other aeration control methods. Reed et al. (1998) found a similar benefit with these simple controllers for fall-harvested corn. This more efficient cooling regime means a simple controller pays for itself in one or two storage seasons.

Future flat bottom steel bins need to be made self-cleaning using advanced aeration system designs to eliminate insect harborages. Self-cleaning systems have been designed for flat-bottomed bins (Kachru, 1991). Immigration of insects into bins is generally a slower process than population growth in warm grain from existing insect infestations in poorly cleaned bins. For those grain storage managers of flat bottom bins that prefer to enter a confined space to do careful vacuuming and sanitizing, such a system is not needed. For others, these systems can eliminate one of the primary sources of insect infestations in stored grain.

Sealing Standards Research Needed

There are two different criteria to consider for a sealed bin standard. First, the pressure half-life (i.e., Australian) standard requires maintaining a specified pressure above atmospheric for a minimum time. However, for CA storage with CO_2, a lesser standard that allows for the absence of any pressures above atmospheric could be adequate. Avoiding gravity leakage from the bottom of the bin may suffice. Research can establish what level is appropriate for these standards, as well as whether one will be superior in practice or whether they should both be available as alternative standards.

Modeling of CA and fumigation applications can effectively supplement experimental work that has been done. Such tools will be valuable for planning efficient bin treatments. Recent developments in modeling CO_2 movement are adequate so that further work on applications can be conducted simultaneous with further validation studies. Modeling of other treatment methods is needed to plan and compare those methods. Additional research is needed to predict the degree of gas-tightness before treatment with CO_2. These models can also be a useful tool for the correct prescription of the CO_2 treatments or methods in advance. Presently, proper treatment can only be determined by trial and error due to the variation in sealing tightness between steel bins.

Continued modeling of temperature, moisture, and insects in stored grain can be the basis for economic evaluation of different geographical (climatic) needs. This will be an important step to specifying effective geographically specific storage systems and management practices, which is necessary because of the widely varying needs for storage systems based on climatic differences. In addition, while adequate methods generally exist for sealing the many bin components, research on developing novel, more economical sealing methods and devices will be useful.

Summary

Researchers have established the effectiveness of properly applied fumigation chemicals and controlled atmospheres (CA) for insect control in stored grain. However, current steel bin designs often prevent effective implementation of these insect control methods. Grain bins should be designed with base and sidewalls that can be sealed. Steel bin roofs should be designed to exclude insects; allow movement of fresh air through the headspace; and with roof vents, hatches, and doors that can be quickly sealed during bin treatments. Research can help specify a U.S. bin sealing standard and sealed bin designs capable of meeting that standard, which will facilitate efficient and safe fumigation and, ultimately, the elimination of chemical insect control measures.

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